

Chemistry

for the IB Diploma

SECOND EDITION

OPTIONS

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with additional
online material



Answers to Option A exam-style questions

- 1 a i One of many answers: steel/iron, aluminium etc.
 ii One of many answers: steel-reinforced concrete, glass-reinforced plastic/fibreglass, wood etc. [2]

b MgB_2 : difference in electronegativity = 0.7; average electronegativity = 1.7

Position in bonding triangle is on the border between metallic and ionic.

MgO : difference in electronegativity = 2.1; average electronegativity = 2.4

Position in bonding triangle is in the ionic region.

The bonding in MgB_2 is less ionic and intermediate between ionic and metallic. [3]

- 2 a Iron is lower in the activity series than carbon, so carbon is a stronger reducing agent and is able to reduce iron ions.

Aluminium is higher in the activity series than carbon, so carbon is not a strong enough reducing agent to reduce aluminium ions. [2]

b $\text{Al}^{3+} + 3\text{e}^- \rightarrow \text{Al}$ [1]

c $Q = It$; $Q = 1000 \times 24 \times 60 \times 60 = 8.64 \times 10^7 \text{ C}$

$$\text{moles of electrons} = \frac{8.64 \times 10^7}{96\,500} = 895 \text{ mol}$$

$$\text{moles of aluminium produced} = \frac{895}{3} = 298 \text{ mol}$$

$$\text{mass of aluminium} = 298 \times 26.98 = 8.05 \times 10^3 \text{ g} \quad [3]$$

- 3 a A series of solutions of known concentration is made up. Each solution is put into the ICP-OES spectrometer and the intensity of one particular line in the emission spectrum is measured for each concentration. Emission intensity is plotted against concentration to obtain the calibration curve. [2]

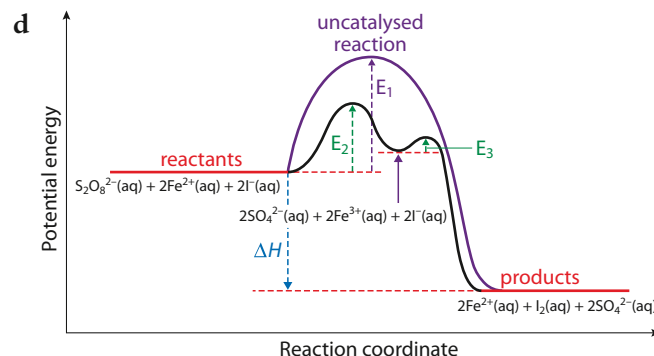
b The intensity is 32. A horizontal line is drawn across from 32 to the line of best-fit and the concentration of nickel is read as $64 \mu\text{g dm}^{-3}$. The total volume of the solution of the sample that was made up was 100.0 cm^3 , i.e. 0.1000 dm^3 . If the concentration of Ni in this solution is $64 \mu\text{g dm}^{-3}$, then in 0.1000 dm^3 there must be 0.1000×64 , or $6.4 \mu\text{g}$.

The mass of shellfish that was originally used was 0.200 g , so we can conclude that this mass of shellfish contains $6.4 \mu\text{g}$ of nickel. In 1.0 g of shellfish there is therefore $(\frac{1}{0.200}) \times 6.4 \mu\text{g}$, or $32 \mu\text{g}$. [3]

4 a $\text{S}_2\text{O}_8^{2-}(\text{aq}) + 2\text{I}^-(\text{aq}) \rightarrow 2\text{SO}_4^{2-}(\text{aq}) + \text{I}_2(\text{aq})$ [1]

b Homogeneous; the catalyst and all reactants are in the same phase (aqueous solutions). [1]

c Fe^{2+} ions are not used up in the overall process – they are used up in step 1 and produced again in step 2. [1]



The activation energy for the uncatalysed pathway is higher than for the catalysed pathway (the catalysed pathway involves the reactions between positive and negative ions, rather than two negative ions as in the uncatalysed reaction); a higher proportion of collisions results in reaction for the catalysed pathway. [4]

- e Zeolites have a cage structure containing a large number of pores (channels and cavities); zeolites can act as size- and shape-selective catalysts because of the pore structure.

Only reactant molecules of less than a certain size or of a certain shape can fit into the channels, and reach the majority of the catalyst active sites or escape from the structure after reaction. [3]

- f Two of: how specific the catalyst is; how efficient the catalyst is; the conditions required for the reaction; how the catalyst is affected by impurities in the reaction mixture; environmental considerations about the use and disposal of the catalyst. [2]

- 5 a *Thermotropic*: pure substance that exhibits liquid crystal properties over a temperature range.
Lyotropic: solution that exhibits liquid crystal properties over a range of concentrations. [2]

b Molecules point, on average, in the same direction; but are positioned randomly relative to each other (no positional order). [2]

c Three of: the substance must be chemically stable; it should exist in the liquid crystal phase over a suitable and wide range of temperatures; the molecules must be polar, so that they change orientation when an electrical field is applied; the molecules must have a rapid switching speed between orientations. [3]

- 6 a i LDPE has much more branching along the polymer chains. [1]

- ii Because of the branching, the chains in LDPE cannot pack together as closely; therefore LDPE is less dense than HDPE; there are weaker London forces between the chains in LDPE; therefore LDPE has a lower tensile strength. [2]
- b i Plasticisation/addition of plasticisers; expansion/conversion into a foam [2]
- ii *Plasticisation* involves the incorporation of small (phthalate) molecules between the polymer chains; increases the flexibility of the polymer.
or
Expansion involves the vaporisation of injected pentane to form gas pockets; increases the shock absorption/insulating properties of the polymer. [2]

7 a propene benzene propanone phenol [4]

$$\text{b Atom economy} = \frac{\text{molar mass of desired product}}{\text{total molar mass of all reactants}} \times 100\%$$

Reaction 1:

$$\text{molar mass of desired product} = 94.12 \text{ g mol}^{-1}$$

$$\text{total molar mass of all reactants}$$

$$= 42.09 + 78.12 + 32.00 = 152.21 \text{ g mol}^{-1}$$

$$\text{atom economy} = \left(\frac{94.12}{152.21} \right) \times 100 = 61.84\%$$

Reaction 2:

$$\text{molar mass of desired product} = 94.12 \text{ g mol}^{-1}$$

$$\text{total molar mass of all reactants}$$

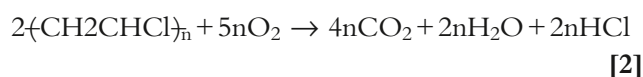
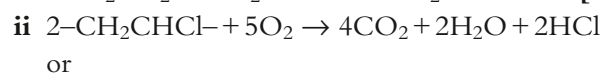
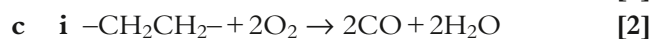
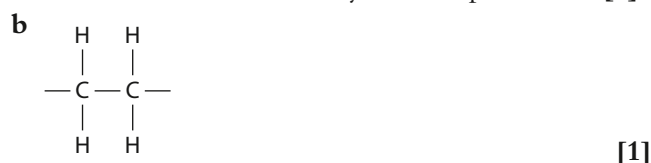
$$= 78.12 + 2.02 + 32.00 = 112.14 \text{ g mol}^{-1}$$

$$\text{atom economy} = \left(\frac{94.12}{112.14} \right) \times 100 = 83.93\%$$

Reaction 2 has a higher atom economy and is therefore more efficient. [4]

- 8 a A mixture of carbon monoxide and iron pentacarbonyl ($\text{Fe}(\text{CO})_5$) is fed into a reaction vessel at high pressure and high temperature. The $\text{Fe}(\text{CO})_5$ decomposes into iron and carbon monoxide. The iron atoms come together to form clusters/nanoparticles on which the carbon nanotubes form in a disproportionation reaction. The iron clusters/nanoparticles act as the catalyst for the formation of the carbon nanotubes. [4]
- b $2\text{CO}(\text{g}) \rightarrow \text{CO}_2(\text{g}) + \text{C}(\text{s})$ [1]
- c i A cylinder made up of hexagons of carbon atoms; each carbon atom forms three covalent bonds to neighbouring atoms. [2]
- ii Capped nanotubes contain pentagons and hexagons of carbon atoms, open nanotubes only contain hexagons. [1]

- 9 a Strong covalent bonds between the atoms would need to be broken and they are non-polar. [1]



iii Dioxins/chlorinated dioxins [1]

iv Low-smoke zero-halogen cabling [1]

- d i They both contain the same bonds, so they have very similar absorbances in their infrared spectrum. [2]

ii This is the range for $\text{C}=\text{O}$, therefore the polymer must contain this group. The only polymer (Table A.3) that contains this bond is PET/PETE, which has RIC 1. [2]

- 10 a Superconductors are materials that have zero electrical resistance below a critical temperature. [1]

b When a superconductor below its critical temperature is exposed to a magnetic field, the movement of electrons on the surface of the material creates a magnetic field that exactly opposes the external field and prevents the penetration of the magnetic field into the material. If the superconductor (originally above its critical temperature) is in a magnetic field and then cooled to below its critical temperature the magnetic field will be expelled. [2]

- 11 a i The simplest repeating unit from which the whole crystal can be built up. [1]

ii Body-centred cubic [1]

iii The structure extends in three dimensions and the coordination number of each atom is the same; the coordination number is 8. [1]

iv Each atom at a corner contributes $\frac{1}{8}$ of an atom and the atom at the centre is completely in the unit cell, therefore the total is $(8 \times \frac{1}{8}) + 1 = 2$ [1]

b The length of the unit cell in a simple cubic lattice is equal to 2 atomic radii; the length of the unit cell is therefore $2 \times 1.67 \times 10^{-10} = 3.34 \times 10^{-10} \text{ m}$
volume of the unit cell $= (3.34 \times 10^{-10})^3$
 $= 3.73 \times 10^{-29} \text{ m}^3$

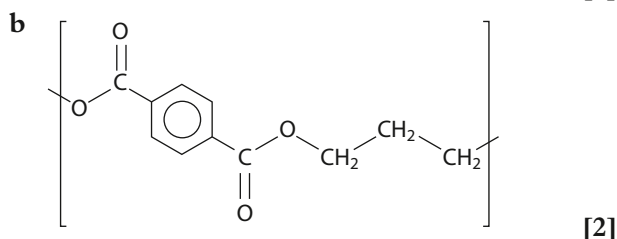
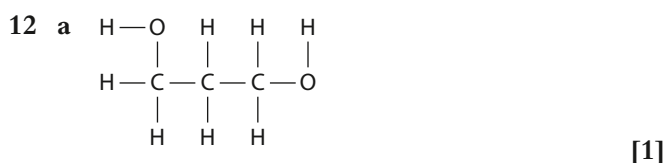
$$\text{mass of one polonium atom} = \frac{209}{6.02 \times 10^{23}} = 3.47 \times 10^{-22} \text{ g}$$

There is one atom in every simple unit cell – the mass of the unit cell = 3.47×10^{-22} g

$$\text{density} = \frac{\text{mass}}{\text{volume}}$$

$$= \frac{3.47 \times 10^{-22}}{3.73 \times 10^{-29}} = 9.31 \times 10^6 \text{ g m}^{-3}$$

There are $1 \times 10^6 \text{ cm}^3$ in 1 m^3 ; so the density in g cm^{-3} is $\frac{9.31 \times 10^6}{10^6}$, i.e. 9.31 g cm^{-3} [6]



c *Advantages:* renewable/does not use up crude oil
Disadvantages: corn starch could be used for food manufacture. [2]

13 a K_{sp} of lead(II) sulfide is the product of the concentrations of the lead ions and sulfide ions in a saturated solution of lead(II) sulfide;
 $K_{\text{sp}} = [\text{Pb}^{2+}(\text{aq})][\text{S}^{2-}(\text{aq})]$. [1]

b $[\text{S}^{2-}(\text{aq})] = \sqrt{(1.25 \times 10^{-28})} = 1.12 \times 10^{-14} \text{ mol dm}^{-3}$ [2]

14 a A ligand that coordinates to a transition metal ion using two atoms; an example is ethane-1,2-diamine, which coordinates using the two nitrogen atoms. [2]

b The chelate effect refers to the higher stability of complexes containing polydentate ligands compared to those containing monodentate ligands with the same donor atom. In the reaction $[\text{Ni}(\text{NH}_3)_6]^{2+} + 3\text{H}_2\text{NCH}_2\text{CH}_2\text{NH}_2 \rightleftharpoons [\text{Ni}(\text{H}_2\text{NCH}_2\text{CH}_2\text{NH}_2)_3]^{2+} + 6\text{NH}_3$ the $[\text{Ni}(\text{H}_2\text{NCH}_2\text{CH}_2\text{NH}_2)_3]^{2+}$ complex is more stable than $[\text{Ni}(\text{NH}_3)_6]^{2+}$; the reaction involves an increase in the number of molecules from left to right; and therefore an increase in entropy – this is the driving force for the reaction. [3]



Answers to Option A test yourself questions

- 1 **a** N – covalent
b M/R boundary – covalent (borderline ionic)
c X/Y boundary – covalent
d M – covalent (borderline ionic)
e R – covalent
f D/E boundary – ionic
- 2 **a** no; **b** yes; **c** no; **d** yes
- 3 **a** $\text{Bi}_2\text{O}_3 + 3\text{C} \rightarrow 2\text{Bi} + 3\text{CO}$; or $2\text{Bi}_2\text{O}_3 + 3\text{C} \rightarrow 4\text{Bi} + 3\text{CO}_2$
b $\text{CuO} + \text{C} \rightarrow \text{Cu} + \text{CO}$; or $2\text{CuO} + \text{C} \rightarrow 2\text{Cu} + \text{CO}_2$
c $\text{Fe}_2\text{O}_3 + 3\text{C} \rightarrow 2\text{Fe} + 3\text{CO}$; or $2\text{Fe}_2\text{O}_3 + 3\text{C} \rightarrow 4\text{Fe} + 3\text{CO}_2$
- 4 **a** $\text{MgCl}_2 \rightarrow \text{Mg} + \text{Cl}_2$
b $2\text{KCl} \rightarrow 2\text{K} + \text{Cl}_2$
- 5 **a** 500 °C; **b** 86 400 °C; **c** 75.6 °C
- 6 **a** 0.0205 mol; **b** 22.4 mol; **c** 0.179 mol
- 7 **a** 2.16 g; **b** 9.07 g; **c** 101 g
- 8 9.2 mg dm^{-3} ; $2.3 \times 10^{-4} \text{ mol dm}^{-3}$
- 9 Molecule I, a rod-shaped, polar molecule
- 10

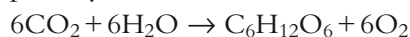
$$\begin{array}{ccccccc}
 \text{CH}_3 & \text{CH}_3 & \text{CH}_3 & \text{CH}_3 & \text{CH}_3 & \text{CH}_3 \\
 | & | & | & | & | & | \\
 -\text{C} & -\text{C} & -\text{C} & -\text{C} & -\text{C} & -\text{C}- \\
 | & | & | & | & | & | \\
 \text{H} & \text{H} & \text{H} & \text{H} & \text{H} & \text{H}
 \end{array}$$

Different forms (atactic/isotactic/syndiotactic) are possible depending on how the methyl groups are arranged relative to the main carbon skeleton.
- 11 Plastic A will be of lower density *and* more flexible: the branches prevent the main parts of the chains getting so close together – hence lower density; there will be weaker forces between the chains – hence more flexible.
- 12 **a** 31.71%; **b** 19.72%; **c** 81.32%
- 13 **a** CO_2 and H_2O
b CO_2 , H_2O and HF
c CO_2 , H_2O , HCN and NO_x
- 14 **a** PCDD; **b** phthalate ester; **c** PCB; **d** phthalate ester; **e** PCB; **f** PCDD
- 15 **a** RIC 6; **b** RIC 1; **c** all; **d** RIC 3
- 16 **a** Face-centred cubic (fcc) – four atoms per unit cell
b Body-centred cubic (bcc) – two atoms per unit cell
c Simple cubic – one atom per unit cell
- 17 14.9° ; 30.9° ; 50.4°
- 18 **a** $4.079 \times 10^{-10} \text{ m}$; **b** 337 pm
- 19 **a** $3.27 \times 10^{-22} \text{ g}$; **b** $1.59 \times 10^{-22} \text{ g}$

Answers to Option B exam-style questions

- 1 a** Catabolism is the breakdown of larger molecules into smaller ones with the release of energy. Anabolism is the process of synthesising the molecules needed by cells – it requires energy. [2]

b i photosynthesis:



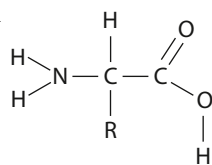
respiration:



ii Photosynthesis is anabolic; respiration is catabolic. [2]

iii Photosynthesis uses up six molecules of carbon dioxide and produces six molecules of oxygen; respiration uses up six molecules of oxygen and produces six molecules of carbon dioxide. These two processes help to maintain the balance between carbon dioxide and oxygen in the atmosphere. [2]

2 a i

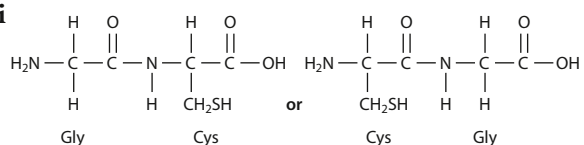


[1]

ii Amino acids exist in their zwitterionic form in the solid state so there are stronger electrostatic attractions between oppositely charged groups on adjacent zwitterions – the COO^- group on one zwitterion attracts the NH_3^+ group on an adjacent zwitterion. [2]

b The sequence of amino acids in the polypeptide chain; the bond is called a peptide bond or amide link. [2]

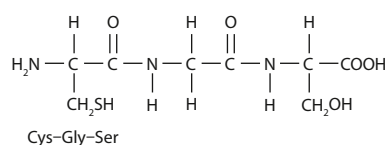
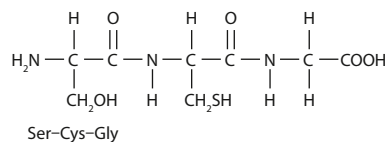
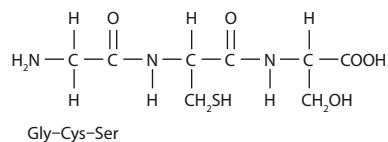
c i



Condensation reaction [2]

ii Two possible dipeptides can be formed; it depends which way round the amino acids are joined. If the COOH group of glycine reacts with the NH_2 group of cysteine, then Gly-Cys will be formed; but if the COOH group of cysteine reacts with the NH_2 group of glycine, then Cys-Gly will be formed. [2]

d Six possible tripeptides. One example should be given – three are shown here:



[2]

e i The acid hydrolyses the peptide bonds to give the individual amino acids. [1]

ii The amino acid mixture is spotted onto some chromatographic paper (usually alongside known amino acids). The paper is suspended in a tank containing a suitable solvent. As the solvent rises up the paper, the amino acids are separated according to their relative solubilities in the solvent (mobile phase) and the water in the chromatographic paper (stationary phase). The paper is dried then sprayed with ninhydrin to locate the positions of the separated amino acids. The R_f values of the amino acids are worked out and compared with those of known amino acids. [4]

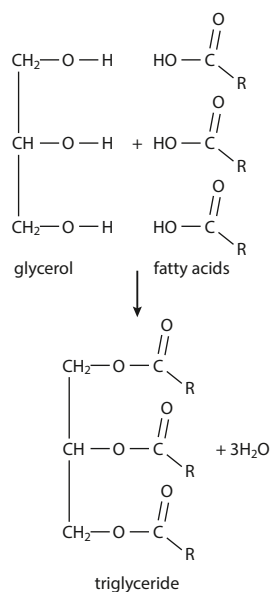
3 a Three of: structural component of cell membranes; energy storage; thermal insulation; electrical insulation; provide a medium in which lipid-soluble vitamins can be transported and stored; hormones. [3]

b i The number of grams of iodine that reacts with 100 g of fat/oil. [1]

$$\text{ii Moles of iodine} = \frac{\text{mass}}{M_r} = \frac{11.43}{253.80} = 0.0450$$

$$\text{Double bonds in fatty acid} = \frac{0.045}{0.015} = 3$$

The fatty acid is polyunsaturated, containing three $\text{C}=\text{C}$ bonds. [3]

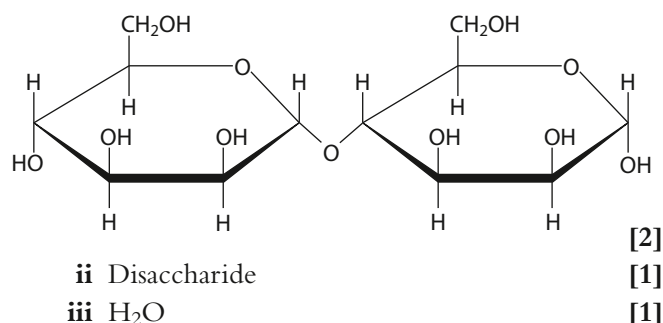


c

[3]

- d Triglycerides with a high proportion of saturated fatty acids have higher melting points due to the long hydrocarbon chains being able to pack closely together, forming stronger intermolecular interactions (London forces). Triglycerides rich in monounsaturated and polyunsaturated fatty acids have lower melting points because the C=C bonds result in the formation of a kink/bend in the hydrocarbon chains; so the hydrocarbon chains cannot approach each other as closely and form as many, or as strong, intermolecular interactions. Polyunsaturated-rich triglycerides have lower melting points than monounsaturated-rich ones. [3]
- e High levels of saturated fat in the diet increase the level of LDL-cholesterol; this can lead to fatty deposits in the walls of arteries in the heart and elsewhere; leading to atherosclerosis (hardening of the arteries), which can result in heart attack/stroke. [3]
- 4 a $C_x(H_2O)_y$; $C_6H_{12}O_6$ [2]
 b Ether [1]
 c i Glycogen [1]
 ii Glucose is a monosaccharide but glycogen is a polysaccharide made up of a large number of glucose units linked by glycosidic bonds; glucose is the monomer and glycogen is a polymer; glycogen has a highly branched structure. [2]

- d i There are several possible answers depending on where the monosaccharides are linked together – the easiest is to form a 1,4-linkage:



- 5 a Ascorbic acid is a water-soluble vitamin; it has many OH groups that can participate in hydrogen bonding with water. [2]
 Retinol is a fat-soluble vitamin; it contains a long hydrocarbon chain and a hydrocarbon ring and, although it contains one OH group, it is mostly non-polar. [2]
- b Three of: make fresh, vitamin-rich food available to everyone; fortify foods with vitamin A by adding vitamin A to foods; biofortification – introduce crops rich in provitamin A to replace other, similar crops; genetic modification to produce crops rich in provitamin A. [3]
- 6 a Compounds that are present in living organisms but should not normally be found there. One environmental problem is the presence of antibiotics in waste water. These are not fully removed from the water in sewage treatment plants and are released into the environment. The release of antibiotics into the environment in waste water can cause damage to aquatic organisms and also result in increased resistance of bacteria to antibiotics. Antibiotics are used to treat a variety of conditions, but if bacteria develop resistance to antibiotics (such as penicillin) these diseases can become much more difficult to cure. [4]
- b A detergent that contains enzymes. Biological washing powders allow stain removal at lower temperatures than non-biological ones and save energy. [2]
- c The increase in concentration of a substance as it passes up the food chain. DDT was used as a pesticide in agriculture and in the control of malaria. DDT in the soil flowed into rivers and lakes. The DDT was taken up by microscopic plants, which were eaten by

microscopic animals, which were eaten by fish, which were eaten by larger fish, which were eaten by birds. At each level the concentration of DDT increased. DDT caused a weakening of the shells of eggs of birds.

or

Heavy metals, such as mercury, can become more concentrated as they move up the food chain. Sources of mercury include waste incineration, gold mining and coal combustion. Mercury finds its way into water supplies where it is absorbed by microorganisms which convert it to methyl mercury (CH_3Hg^+). Its concentration increases as it is passed up the food chain until it reaches large fish such as tuna, which are eaten by humans. Adverse effects of consuming mercury include damage to the central nervous system and there have been worries about the level of mercury present in tuna consumed by humans, especially pregnant women.

[4]

- 7 a They provide an alternative pathway for the reaction, which has a lower activation energy. They also provide an area (the active site) for the reactants to come together so making it more likely that they will react. Enzymes bind temporarily to a substrate at the active site, forming an enzyme–substrate complex. The formation of this complex can cause the substrate molecule to become strained and more ready to form the product, with regeneration of the enzyme.

[3]

- b i Competitive inhibitors usually resemble the natural substrate and compete with it by binding to the active site. If the inhibitor is bound to the active site, it prevents the substrate from binding and the enzyme is inhibited. Non-competitive inhibitors do not compete with the substrate – they do not bind to the active site but bind to another region of the enzyme (allosteric site), which causes a conformational change in the shape of the active site preventing the substrate from binding. [2]
- ii Increasing substrate concentration reduces inhibition by competitive inhibitors but has no effect on non-competitive inhibitors. [2]
- iii Competitive inhibition – V_{max} remains the same, but it will take a higher concentration of substrate to reach V_{max} , so K_m will be higher. Non-competitive inhibition – V_{max} is reduced but K_m is the same. [2]

c Number of moles of $\text{KH}_2\text{PO}_4 = \frac{15.00}{136.09}$
 $= 0.1102 \text{ mol}$

Number of moles of $\text{K}_2\text{HPO}_4 = \frac{15.00}{174.18}$
 $= 0.08612 \text{ mol}$

$[\text{base}] = 0.08612 \text{ mol dm}^{-3}$;
 $[\text{acid}] = 0.1102 \text{ mol dm}^{-3}$

$\text{pH} = \text{p}K_a + \log_{10} \left(\frac{[\text{base}]}{[\text{acid}]}} \right)$

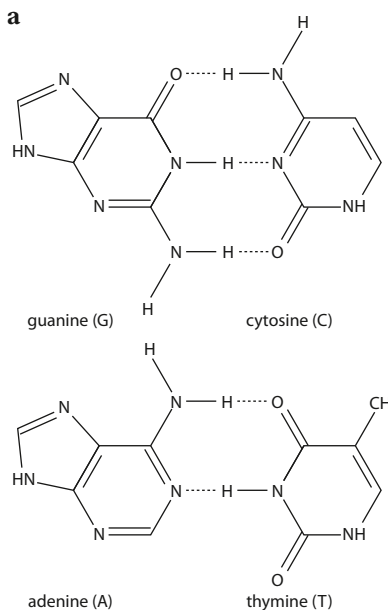
$\text{pH} = 7.21 + \log_{10} \left(\frac{0.08612}{0.1102} \right)$

$= 7.21 + \log_{10} 0.7815$

$= 7.10$

[3]

8 a



[3]

- b Two of: DNA is a double-stranded nucleic acid, whereas RNA is single stranded; DNA contains the nucleotide base thymine, whereas RNA contains uracil; DNA contains 2-deoxyribose sugar, whereas RNA contains ribose. [2]
- c i It has genetic material that has been changed in some way by genetic engineering. Genetic modification usually involves the insertion or deletion of specific genes in the genetically modified organism. [2]
- ii There are many possible answers.
Benefits – increased nutritional content of crops; increased yield of crops; ability of crops to grow in adverse conditions; improved crop resistance to disease, drought, pests and herbicides; enhanced taste, texture, quality and shelf life; production of ‘healthy’ crops; improved animal health through development of animals that are more resistant to disease; improved conservation of water, soil and energy.

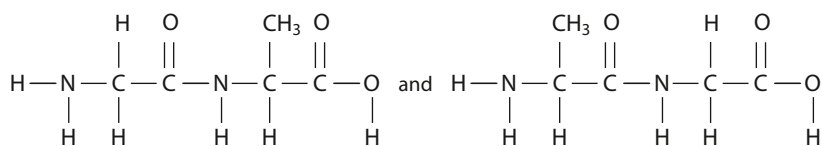
Concerns – not enough is known about long-term effects; escape of transgenic material into the ‘wild’; allergies – worries that GM foods could cause more/different allergies; damage to the environment and unbalancing of ecosystems; alteration of the composition of a balanced diet – by changing the nutritional content and quality of foods; exploitation and monopolisation – by countries and companies with intellectual property rights to the technology; ethical considerations – include tampering with nature, ‘playing God’.

- 9 a A coloured compound produced by metabolism. [1]
 b The oxidation number of iron is +2 in hemoglobin not bound to oxygen. [1]
 c Heme has a long conjugated system of alternating single and double bonds/delocalised system. It absorbs light in the visible region of the spectrum to promote electrons from lower to higher energy levels. [2]
 d This is a sigmoidal curve. When the partial pressure of oxygen is low, hemoglobin has a low affinity for oxygen, but the affinity increases markedly as the partial pressure of oxygen increases – the gradient of the curve increases. It becomes easier for oxygen to bind to hemoglobin when some oxygen molecules have already bound to the iron – the binding of oxygen is cooperative. Hemoglobin has a tetrameric structure with four iron–heme complexes. The binding of oxygen to one of the iron ions in the tetramer changes the shape (conformation) of the protein in such a way that it becomes easier for oxygen molecules to bind to the other sites. [3]
 e Decrease in pH and increase in concentration of carbon dioxide both decrease the ability of hemoglobin to bind oxygen. The H^+ binds to an amino-acid side-chain in a polypeptide chain. Binding of H^+ changes the shape (conformation) of the protein slightly to reduce its affinity for oxygen.
 Carbon dioxide dissolves to form an acidic solution (carbonic acid, H_2CO_3). This lowers the pH so that more H^+ binds to hemoglobin and causes a release of oxygen from the hemoglobin. Carbon dioxide also binds to hemoglobin on the polypeptide chain. This process has two effects – it forms H^+ and changes the shape of the protein; both of these reduce the affinity of hemoglobin for oxygen. The binding of H^+ and CO_2 are both allosteric effects. [5]

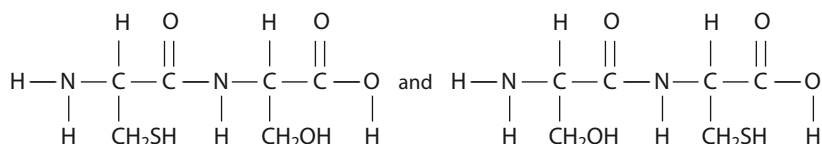
- 10 a
$$\begin{array}{c} H \\ | \\ H_2N - C - COOH \\ | \\ H \end{array}$$
 [1]
 b L-configuration [1]
 c i D; the OH on the carbon above the CH_2OH group is on the right. [1]
 ii D; the OH on the carbon above the CH_2OH group is on the right. [1]
 d When the sugar cyclises, a new chiral centre is formed on C1. The OH attached to C1 can either be below the ring (on the opposite side to the CH_2OH attached to C5) (α -glucose) or above the ring (on the same side as the CH_2OH attached to C5) (β -glucose). [3]
 e Starch is a polymer of α -glucose whereas cellulose is a polymer of β -glucose. Starch contains α -1,4-glycosidic linkages and α -1,6-glycosidic linkages whereas cellulose only contains β -1,4 glycosidic linkages. Cellulose has no branching in the chain but amylopectin has branches. [3]
 f *Cis*-retinal joins to the protein opsin to form rhodopsin. When photons of light are absorbed by the retinal in rhodopsin, the retinal changes to the all-*trans* form. This changes the conformation of the protein, which triggers a series of events that result in signals being sent to the brain. Once a signal has been sent to the brain, the *trans*-retinal dissociates from the opsin and is replaced by another *cis*-retinal molecule. The *trans*-retinal molecule that dissociated is converted to *cis*-retinal again by an enzyme. [5]

Answers to Option B test yourself questions

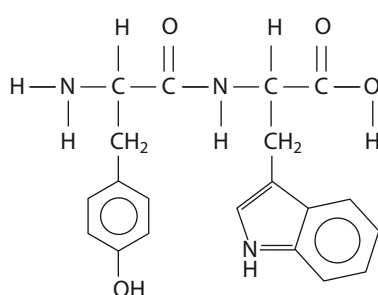
1 a



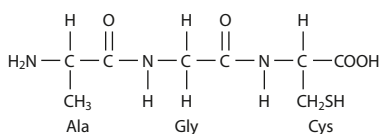
b



2



3



4 Asp-His-Leu; Asp-Leu-His; His-Asp-Leu; His-Leu-Asp; Leu-Asp-His; Leu-His-Asp

5 Phenylalanine (Phe); serine (Ser); histidine (His); alanine (Ala)

6 A: 0.24

B: 0.67

C: 0.49

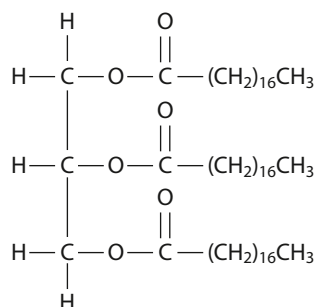
D: 0.89

E: 0.38

7 Arginine and lysine

8 All are false (A is partially true)

9



10 $\text{CH}_3(\text{CH}_2)_{14}\text{COOH}$; $\text{CH}_3(\text{CH}_2)_{18}\text{COOH}$; $\text{CH}_3(\text{CH}_2)_{20}\text{COOH}$; and $\text{CH}_2(\text{OH})\text{CH}(\text{OH})\text{CH}_2(\text{OH})$

11 $\text{C}_{17}\text{H}_{33}\text{COOH} < \text{C}_{17}\text{H}_{35}\text{COOH} < \text{C}_{19}\text{H}_{39}\text{COOH} < \text{C}_{21}\text{H}_{43}\text{COOH}$

12 **a** saturated; **b** polyunsaturated; **c** monounsaturated

13 **a** 180; **b** 20; **c** 100

14 **a** 0 double bonds; iodine number 0

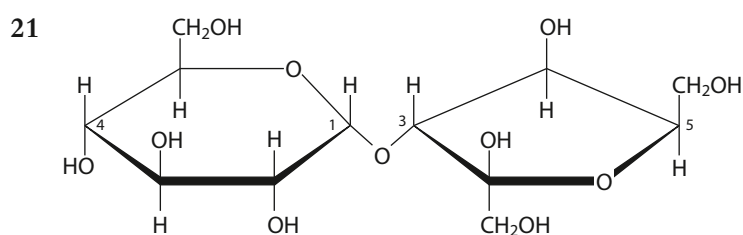
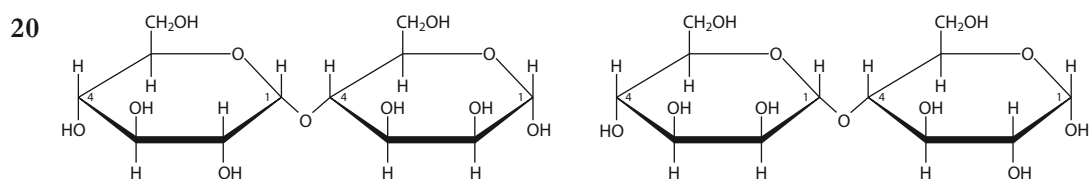
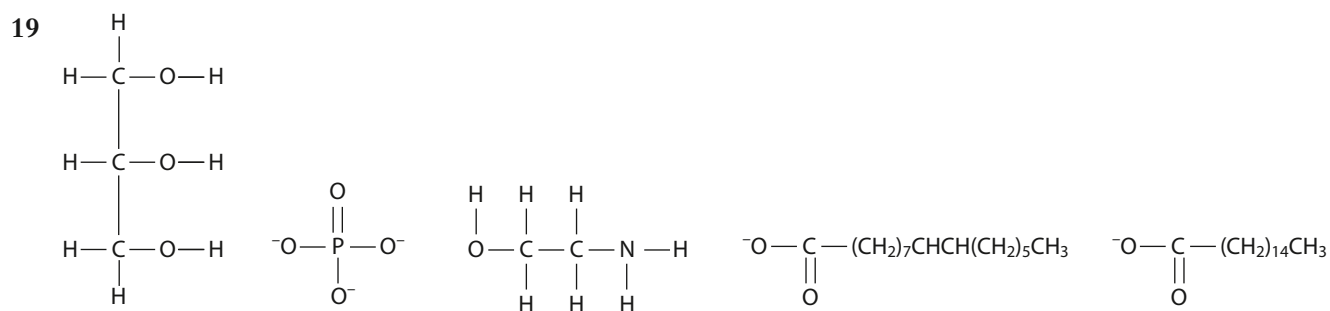
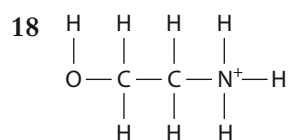
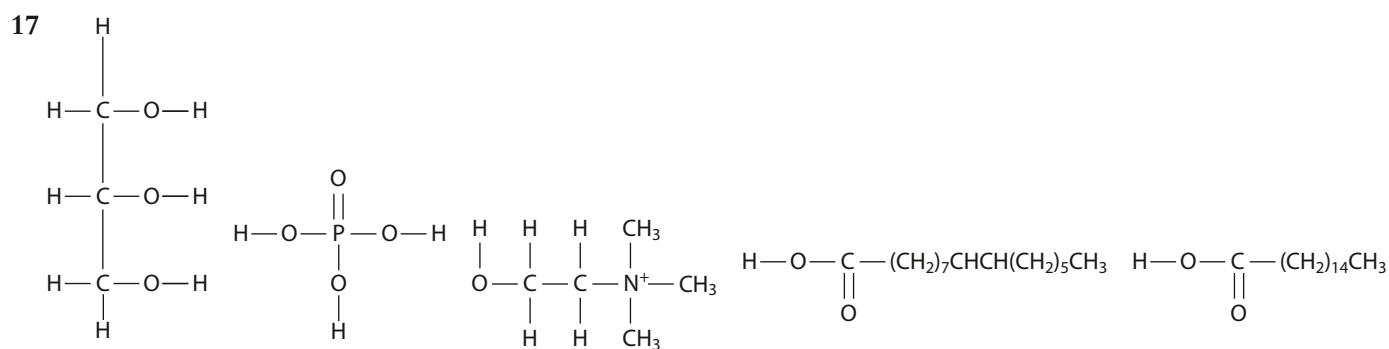
b 4; 409

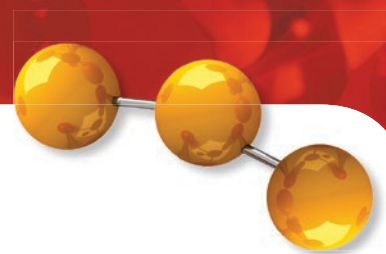
c 1; 90

d 2; 165

15 One C=C bond

16 Two C=C bonds





- 22 **a** fat-soluble; **b** water-soluble
- 23 **a** 31.71%; **b** 19.72%; **c** 81.32%
- 24 $V_{\max} = 6.0 \times 10^{-4} \text{ mol dm}^{-3} \text{ s}^{-1}$ (60×10^{-5})
 $K_m = 3 \times 10^{-4} \text{ mol dm}^{-3}$ (0.3×10^{-3})
[answers in range $3\text{--}4 \times 10^{-4} \text{ mol dm}^{-3}$]
- 25 X
- 26 **a** 4.82; **b** 4.47; **c** 4.98; **d** 4.76; **e** 4.46; **f** 8.95
- 27 **a** $0.275 \text{ mol dm}^{-3}$; **b** 4.19
- 28 **a** 4.8 ppm; **b** 2.8 ppm; **c** 7.2 ppm
- 29 **a** $6.2 \times 10^{-4} \text{ mol dm}^{-3}$; **b** $3.6 \times 10^{-3} \text{ mol dm}^{-3}$;
c $1.8 \times 10^{-4} \text{ mol dm}^{-3}$
- 30 **a** A–A–G–C–C–T–G
b T–T–T–G–C–G–G–A–T–A–A–A–C–T–G–G
- 31 **a** A–G–U–U–C–A
b C–C–C–A–A–U–G–A–C–G–G–U
- 32 B (longer conjugated system)
- 33 **a** false; **b** true; **c** false; **d** true; **e** true; **f** false
- 34 **a** L; **b** D; **c** D
- 35 **a** D; **b** L; **c** D
- 36 Alpha
- 37 Condensation; α -1,4-glycosidic linkage

Answers to Option C exam-style questions

- 1 a** Renewable energy sources are replenished naturally— they will not run out.
Non-renewable energy sources are finite – they will eventually run out. [2]
- b** *Advantage* – one of:
energy from the sun is free/
non-polluting in use/
does not produce greenhouse gases/
can be useful in remote locations.
Disadvantage – one of:
not a very concentrated form of energy/
huge banks of solar cells/panels are required/
solar cells are expensive to manufacture and buy/
a lot of energy and resources needed in manufacture, which can produce pollution/
dependent on weather and do not produce electricity at night. [2]
- c i** Total amount of energy from combustion of 10.0 mol of hydrogen is:
 $10.0 \times 286 = 2860 \text{ kJ}$
Efficiency (%) = $\left(\frac{\text{useful energy out}}{\text{total energy in}} \right) \times 100$
 $= \left(\frac{1500}{2860} \right) \times 100 = 52.4\%$ [2]
- ii** Relative molecular mass of methanol = 32.05
volume occupied by 1 mol of methanol = $\frac{32.05}{0.79} = 41 \text{ cm}^3$ or 0.041 dm^3
Energy density = $\frac{726}{0.041} = 18\,000 \text{ kJ dm}^{-3}$ [3]
- iii** Although methanol has a lower specific energy, it is a liquid at room temperature, whereas hydrogen is a gas. Methanol therefore has a much higher energy density and a smaller space is needed to store the fuel. [2]
- 2 a** The process is called fractional distillation – separation depends on the different fractions having different boiling points.
The crude oil is heated in a furnace.
The liquid–vapour mixture is passed into a fractionating tower which is hot at the bottom and cooler at the top.
Gaseous compounds travel up the column until they condense and are drawn off as liquids.
Compounds with lower boiling points are drawn off higher up the tower. [4]
- b i** Octane number is a measure of the tendency of a fuel not to undergo auto-ignition/cause knocking in an engine.
The higher the octane number, the lower the tendency for auto-ignition. [1]
- ii** Catalytic cracking involves breaking long-chain hydrocarbons into shorter ones.
Short-chain alkanes have a higher octane number than longer chain ones and so cracking increases the octane number of a petroleum fraction.
Alkenes are also produced in cracking reactions and these have a higher octane number than the equivalent alkanes.
Catalytic cracking also increases the octane number because it produces more branched-chain alkanes and aromatic compounds, which have higher octane numbers than straight-chain alkanes. [3]
- c i** Total amount of fuel consumed = $5570 \times 14.0 = 77\,980 \text{ dm}^3$
Total amount of CO_2 produced = $77\,980 \times 2.00 = 155\,960 \text{ kg}$
Amount of CO_2 produced per passenger = $\frac{155\,960}{500} = 312 \text{ kg}$
Carbon footprint = $312 \text{ kg CO}_2\text{e}$ [3]
- ii** The total volume of fuel consumed for the journey is $\left(\frac{5570}{100} \right) \times 13 = 724.1 \text{ dm}^3$
The mass of fuel burned can be calculated from the density:
mass = density \times volume
 $0.700 \times 724\,100 = 506\,870 \text{ g}$
Number of moles of octane is $\frac{506\,870}{114.26} = 4436 \text{ mol}$
The equation for the combustion of octane is:
 $\text{C}_8\text{H}_{18}(\text{l}) + \frac{25}{2} \text{O}_2(\text{g}) \rightarrow 8\text{CO}_2(\text{g}) + 9\text{H}_2\text{O}(\text{l})$
So $8 \times 4436 = 35\,489 \text{ mol CO}_2$ are produced.
The mass of CO_2 produced is $35\,489 \times 44.01 = 1.562 \times 10^6 \text{ g}$ or 1562 kg .
The carbon footprint per person is therefore $\frac{1562}{2} = 781 \text{ kg CO}_2\text{e}$ [5]

3 a Nuclear fission is the breakdown of a large nucleus into two smaller fragments of comparable masses. [1]

b If uranium-235 undergoes a fission reaction it breaks apart into two nuclei with higher binding energies per nucleon (more stable nuclei). A fusion reaction would involve the formation of a nucleus with a lower binding energy per nucleon. [2]

c The mass numbers and atomic numbers must balance on both side of the equation. The total mass number on the left is 236 and that on the right (without the neutrons) is $135 + 99 = 234$. Therefore there must be two neutrons. [1]

d i The time it takes for the number of radioactive nuclei present in a sample at any given time to fall to half its value.

ii The amount present halves every 1.7 s

$$100\% \xrightarrow{1.7\text{ s}} 50\% \xrightarrow{1.7\text{ s}} 25\% \xrightarrow{1.7\text{ s}} 12.5\% \xrightarrow{1.7\text{ s}} 6.25\%$$

6.8 s is equivalent to four half-lives; so the amount of antimony-135 remaining is 6.25% of the amount originally present. [2]

e Three of: *Health* – exposure to radiation can cause serious problems such as radiation sickness and cancer, which can result in death.

Accidents – can result in meltdown and escape of radioactive material into the environment.

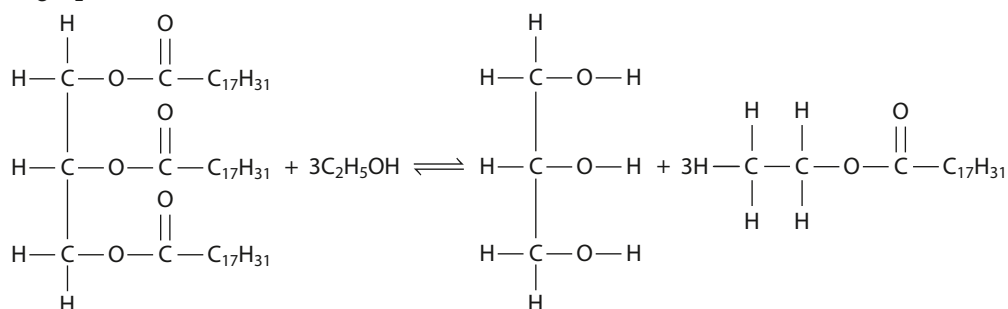
Disposal of waste – there is currently no completely safe way of disposing of high-level nuclear waste.

Security – nuclear fuels from reprocessing plants could be stolen and used in making nuclear weapons. [3]

4 a The long conjugated system of alternating double and single bonds. [1]

b $6\text{CO}_2 + 6\text{H}_2\text{O} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2$ [1]

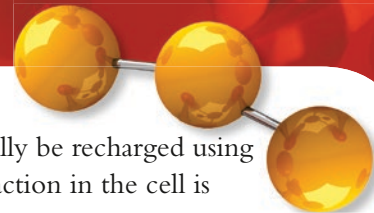
c i



[2]

ii Sunflower oil has a much higher relative molecular mass and therefore there are stronger London forces between its molecules than in biodiesel.

Stronger intermolecular forces means a decreased tendency to flow. [2]



- d** There are many possible answers here – for example:
Advantage – one of:
 Biofuels are renewable and so will not run out, but fuels derived from petroleum are finite.
 Biodiesel is biodegradable so there is less environmental impact from a major spillage.
 Biodiesel contains no sulfur so there are no sulfur dioxide emissions when it is burned.
Disadvantage – one of:
 Biodiesel is more expensive than petrodiesel.
 Biodiesel releases less energy per gram than petrodiesel when burned.
 Growing crops that will be converted to biofuels requires vast areas of land that could be used for growing food crops. [2]
- 5 a i** In CO_2 and CH_4 , certain stretching and bending modes cause a change in dipole moment and they are able to absorb IR radiation.
 N_2 and O_2 are non-polar diatomic molecules and can only undergo symmetrical stretching which does not cause a change in dipole moment. [3]
- ii** Some of the short wavelength solar radiation from the Sun passes through the atmosphere to reach the Earth's surface.
 The surface absorbs some of this radiation and heats up.
 The warmed surface radiates longer wavelength, infrared radiation.
 Some of this radiation is absorbed by greenhouse gases such as CO_2 in the atmosphere.
 Of the radiation absorbed by the greenhouse gases, some is re-radiated back to Earth.
 The overall effect is that heat is 'trapped' by some gases in the atmosphere. [4]
- iii** Large-scale burning of fossil fuels/deforestation/increased agriculture have increased the amount of carbon dioxide and other greenhouse gases in the atmosphere.
 A consequence of this is global warming/climate change. [3]
- b** Carbon dioxide is the most abundant greenhouse gas; but methane is much better than carbon dioxide at absorbing infrared radiation. [2]
- c** Particulates in the atmosphere cause sunlight to be reflected back into space, which causes cooling of the Earth. [2]
- 6 a** Because the batteries are of the same type they will produce the same voltage; however, a bigger battery is likely to contain more materials and so should last longer. [1]
- b i** Primary cells cannot usually be recharged using mains electricity – the reaction in the cell is non-reversible.
 The chemical reactions in a rechargeable battery are reversible and can be reversed by connecting the battery to an electricity supply. [2]
- ii** *Anode:* $\text{Cd(s)} + 2\text{OH}^-(\text{aq}) \rightarrow \text{Cd(OH)}_2(\text{s}) + 2\text{e}^-$; oxidation
Cathode: $2\text{NiO(OH)(s)} + 2\text{H}_2\text{O(l)} + 2\text{e}^- \rightarrow 2\text{Ni(OH)}_2(\text{s}) + 2\text{OH}^-(\text{aq})$; reduction [3]
- c** They are very heavy and do not produce much energy per kilogram, so enough batteries to power a vehicle would add greatly to the overall mass of the vehicle. [2]
- d** $Q = \frac{1}{[\text{Cu}^{2+}(\text{aq})]} = \frac{1}{0.800} = 1.25$
 The number of electrons transferred is 2 and so we have:
 $E = E^\ominus - \left(\frac{RT}{nF}\right) \ln Q$
 $= 0.34 - \left(\frac{8.31 \times 292}{2 \times 96\,500}\right) \ln 1.25$
 $= 0.34 \text{ V}$
 To two significant figures the answer comes out the same as the literature value, therefore the small variations in temperature and concentration cannot explain the difference between the student's value and the literature value. [3]
- 7 a** Mass defect is the difference between the mass of a nucleus and the sum of the masses of the individual nucleons.
 Nuclear binding energy is the energy required to break apart a nucleus into protons and neutrons. [2]
- b** The nucleus is composed of just one particle – a proton. [1]
- c i** A tritium atom contains one electron. The mass of the nucleus is calculated by subtracting the mass of the electron from the mass of the atom:
 mass of tritium nucleus = $3.016\,05 - 0.000\,548\,6 = 3.015\,501\,4 \text{ u}$ [1]
- ii** Mass defect = mass of (protons + neutrons) – mass of nucleus
 $\Delta m = (1.007\,276 + 2 \times 1.008\,665) - 3.015\,501\,4 = 0.009\,104\,6 \text{ u}$
 To convert to kg we multiply by the mass of 1 u, given in the IB Chemistry data booklet as $1.66 \times 10^{-27} \text{ kg}$:
 mass defect = $0.009\,104\,6 \times 1.66 \times 10^{-27} = 1.51 \times 10^{-29} \text{ kg}$ [2]
- Note:** This answer has been rounded to three significant figures but the answer with more significant figures will be carried through to the next part of the question.

- iii Using $E = mc^2$ we can convert the mass defect to the equivalent amount of energy:

$$E = 1.51 \times 10^{-29} \times (3.00 \times 10^8)^2 = 1.36 \times 10^{-12} \text{ J}$$

This is the nuclear binding energy – to work out the binding energy per nucleon this must be divided by the total number of nucleons:

$$\frac{1.36 \times 10^{-12}}{3} = 4.53 \times 10^{-13} \text{ J} \quad [2]$$

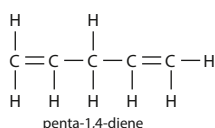
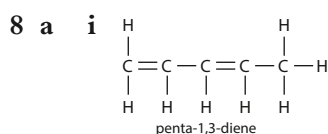
- d Total mass of the reactants = $3.01605 + 3.01605 = 6.0321 \text{ u}$
 Total mass of products = $4.00260 + 2 \times 1.008665 = 6.01993 \text{ u}$
 Decrease in mass = $6.0321 - 6.01993 = 0.01217 \text{ u}$
 This must be converted to kg:
 $0.01217 \times 1.66 \times 10^{-27} = 2.02 \times 10^{-29} \text{ kg}$
 $E = mc^2 = 2.02 \times 10^{-29} \times (3.00 \times 10^8)^2 = 1.82 \times 10^{-12} \text{ J}$
 The energy released per mole is:
 $1.82 \times 10^{-12} \times 6.02 \times 10^{23} = 1.09 \times 10^{12} \text{ J mol}^{-1}$, or
 $1.09 \times 10^9 \text{ kJ mol}^{-1}$
- e $\lambda = \frac{\ln 2}{t_{1/2}} = \frac{0.6931}{12.26} = 0.05654 \text{ y}^{-1} \quad [4]$

Note: This answer has been rounded to four significant figures but more figures have been carried through for further calculations.

$$\frac{N}{N_0} = e^{-\lambda t} = e^{-0.05654 \times 20.00} = 0.3228$$

This is multiplied by $100.0 \mu\text{g}$ to get the mass remaining: $32.28 \mu\text{g} \quad [3]$

- f i The rate of effusion depends on the molar mass; the molecule that will effuse most slowly is $^3\text{H}-^3\text{H}$ because this has the highest molar mass; the one that will effuse most quickly is $^1\text{H}-^1\text{H}$. $[2]$
- ii rate of effusion of gas $^1\text{H}_2 = \frac{\sqrt{\text{molar mass of gas } ^3\text{H}_2}}{\sqrt{\text{molar mass of gas } ^1\text{H}_2}}$
 $= \frac{\sqrt{6.0321}}{\sqrt{2.01565}} = 1.73$
 $^1\text{H}_2$ will effuse 1.73 times quicker than $^3\text{H}_2 \quad [2]$



$[2]$

- ii Penta-1,3-diene will absorb the longer wavelength of UV radiation because the double bonds are conjugated. The double bonds in penta-1,4-diene are separated by two

single bonds, so they are not conjugated and delocalisation is not possible. Penta-1,3-diene has a longer conjugated system, and so a smaller energy gap between lower and upper molecular orbitals. This means that lower energy radiation (longer wavelength) must be absorbed to promote an electron to a higher molecular orbital in penta-1,3-diene. $[3]$

- iii **X** is coloured because it has the longer conjugated/delocalised system. The conjugated system in **X** extends over the whole molecule, but in **Y** there are three single bonds in a row in the middle of the molecule and the conjugated system is broken. The conjugated system in **X** is long enough for it to absorb visible light and so it appears coloured. **Y** absorbs only UV radiation and is therefore colourless. $[4]$

- b The energy from photons of light causes electrons to be promoted from the valence band to the conduction band, where they are free to move. Holes in the valence band are also generated, and these can also move. $[2]$
- c Light causes electrons in the dye sensitizer to be promoted to a higher energy level. The electrons are transferred to the conduction band of TiO_2 nanoparticles. The sensitizer has now been oxidised and is reduced back to its original state by electrons from the I^- ions in the electrolyte. The electrons at high energy in the conduction band of the TiO_2 flow through the external circuit to the cathode, where they reduce the I_3^- ions back to I^- . $[4]$

Answers to Option C test yourself questions

1 a 70%; b 18%

2 40%

3 a 22.7 kJ g^{-1} ; b 48.3 kJ g^{-1} ; c 33.2 kJ g^{-1}

4 a 35.9 kJ dm^{-3} ; b 52.5 kJ dm^{-3} ; c $39\,600 \text{ kJ dm}^{-3}$;
d $23\,400 \text{ kJ dm}^{-3}$

5 a M; b P; c Q

6 a $\text{C}_{13}\text{H}_{28} \rightarrow \text{C}_8\text{H}_{18} + \text{C}_5\text{H}_{10}$

b $\text{C}_{10}\text{H}_{22} \rightarrow \text{C}_6\text{H}_{14} + \text{C}_4\text{H}_8$

c $\text{C}_{16}\text{H}_{34} \rightarrow \text{C}_9\text{H}_{18} + \text{C}_7\text{H}_{16}$

7 a *Ethanol*: 1.910 g of CO_2 released per gram of ethanol burned

0.06439 g of CO_2 released per kJ of energy released

b *Hexane*: 3.063 g of CO_2 released per gram of hexane burned

0.06343 g of CO_2 released per kJ of energy released

8 a 43.3 kg CO_2e ; b 248 kg CO_2e

9 a $^{235}_{92}\text{U} + ^1_0\text{n} \rightarrow ^{236}_{92}\text{U} \rightarrow ^{140}_{55}\text{Cs} + ^{93}_{37}\text{Rb} + 3^1_0\text{n}$

b $^{235}_{92}\text{U} + ^1_0\text{n} \rightarrow ^{236}_{92}\text{U} \rightarrow ^{105}_{42}\text{Mo} + ^{129}_{50}\text{Sn} + 2^1_0\text{n}$

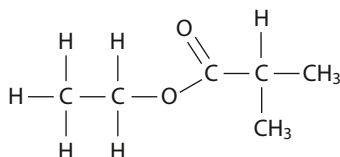
10 a $^{121}_{48}\text{Cd}$; b $^{96}_{40}\text{Zr}$

11 a 25 mg; b 6.25 mg; c 0.0980 mg

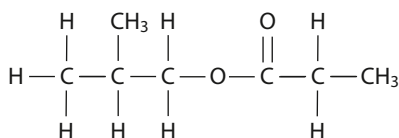
12 a 45 days; b $7 \times 10^{11} \text{ y}$

13 a 800 y; b 168 d

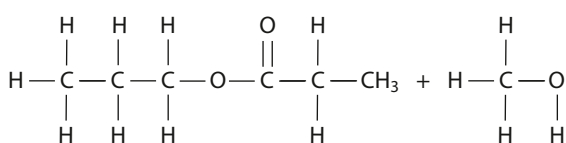
14 a



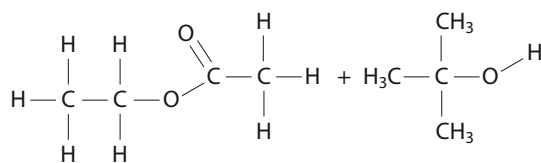
b



15 a



b



16 HCN, HF, CO, CO_2 , H_2S , CFCl_3 , N_2O

17 Three of: carbon dioxide; methane; nitrous oxide [nitrogen(I) oxide]; chlorofluorocarbons

18 a false; b false; c true; d true

19 a $\text{PbSO}_4(\text{s}) + 2\text{e}^- \rightarrow \text{Pb}(\text{s}) + \text{SO}_4^{2-}(\text{aq})$

b $\text{Ni}(\text{OH})_2(\text{s}) + \text{OH}^-(\text{aq}) \rightarrow \text{NiO}(\text{OH})(\text{s}) + \text{H}_2\text{O}(\text{l}) + \text{e}^-$

20 $6\text{C} + \text{Li}_x\text{CoO}_2 \rightarrow \text{Li}_x\text{C}_6 + \text{CoO}_2$

21 a -0.17 V ; b 0.68 V ; c 0.81 V ; d 1.82 V ; e -0.77 V

22 a 1.17 V ; b 1.32 V ; c 1.35 V

23 a 0.39 V ; b 1.07 V ; c 0.58 V

24 a 0.06 V ; b 0.03 V ; c 0.04 V ; d 0.09 V

25 a mass defect 0.069511 u

binding energy $1.04 \times 10^{-11} \text{ J}$

binding energy per nucleon 6.48 MeV

b mass defect 0.20028 u

binding energy $2.99 \times 10^{-11} \text{ J}$

binding energy per nucleon 8.12 MeV

c mass defect 0.52845 u

binding energy $7.90 \times 10^{-11} \text{ J}$

binding energy per nucleon 8.80 MeV

d mass defect 1.9398 u

binding energy $2.90 \times 10^{-10} \text{ J}$

binding energy per nucleon 7.57 MeV

26 a $3.89 \times 10^8 \text{ kJ mol}^{-1}$; b $1.70 \times 10^9 \text{ kJ mol}^{-1}$

27 a $1.68 \times 10^{10} \text{ kJ mol}^{-1}$; b $1.84 \times 10^{10} \text{ kJ mol}^{-1}$

28 a 0.012 min^{-1} ; b $8.04 \times 10^{-3} \text{ d}^{-1}$; c $3.30 \times 10^{-16} \text{ y}^{-1}$

29 a 134 minutes (135 minutes if all figures are carried through on the calculator); b 200 days; c 4.9×10^{15} years

30 a 29.8%; b 16.4%

31 Half-life = $1.33 \times 10^6 \text{ s}$ or 15.4 days

Mass left = $0.301 \mu\text{g}$

32 a helium effuses at 4.00 times the rate of sulfur dioxide

b ethene effuses at 1.25 times the rate of propane

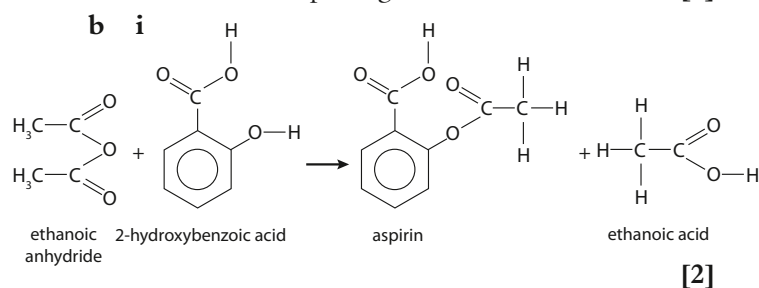
c hydrogen effuses at 2.82 times the rate of methane

- 33** **a** 32.1 g mol^{-1} ; **b** 26.0 g mol^{-1} ; **c** 27.0 g mol^{-1}
- 34** **a** $3.85 \times 10^{-3} \text{ mol}$ methane and $2.69 \times 10^{-3} \text{ mol}$ helium
- b** $4.14 \times 10^{-3} \text{ mol}$ carbon monoxide and $4.31 \times 10^{-3} \text{ mol}$ carbon dioxide
- c** $3.56 \times 10^{-3} \text{ mol}$ fluorine and $3.94 \times 10^{-3} \text{ mol}$ chlorine
- 35** (shortest wavelength) $\text{II} < \text{V} < \text{IV} < \text{I} < \text{III} < \text{VI}$
- 36** **a** p-type; **b** p-type; **c** n-type; **d** n-type

Answers to Option D exam-style questions

- 1 a i** *Therapeutic effect*: a desirable and beneficial effect; one that alleviates symptoms or treats a particular disease. [1]
- ii** *Side effect*: an unintended secondary effect of the drug on the body (usually undesirable). [1]
- iii** *Tolerance*: the body becomes less responsive to the effects of the drug and so larger and larger doses are needed to produce the same effect. [1]
- iv** *Bioavailability*: the fraction of the administered drug that reaches the general blood circulation (or the fraction of the administered drug that reaches the target part of the human body). [1]
- b** The range of doses of a drug (or range of concentrations of drug in the blood plasma) that gives safe, effective therapy.
or
The range of dosage between the minimum required to cause a therapeutic effect and the level which produces unacceptable toxic effects. [1]
- c i** Intravenous injection; the drug is injected directly into the bloodstream, where it can then be transported round the body to reach its site of action. [2]
- ii** Pulmonary route/inhalation [1]

- 2 a** Aspirin intercepts the pain stimulus at the source of the pain by inhibiting the production of pain mediators called prostaglandins. [1]



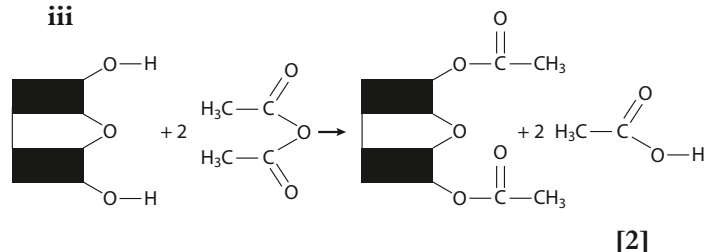
- ii** Number of moles of salicylic acid

$$= \frac{5.00}{138.13} = 0.0362 \text{ mol}$$
 Relative molecular mass of aspirin = 180.17
 Theoretical yield of aspirin = $180.17 \times 0.0362 = 6.52 \text{ g}$
 Percentage yield = $\frac{\text{actual yield}}{\text{theoretical yield}} \times 100$

$$= \frac{5.02}{6.52} \times 100 = 77.0\%$$
 [3]
- iii** Aspirin has a higher relative molecular mass than salicylic acid, therefore the same number of moles has a greater mass. [1]

- iv** Aspirin can be purified by recrystallisation. Impure aspirin is dissolved in the minimum amount of hot solvent to form a close-to-saturated solution. The solution is filtered while still hot to remove any insoluble impurities. The solution is allowed to cool. The solid product is removed from the solution by filtration. The solid product is dried. [4]
- c** Penicillins prevent the bacteria from forming cross-links in the sugar-peptide layer of the cell wall. This results in a weakened cell wall, and the bacterial cell bursts owing to osmotic pressure caused by water entering the cell. [2]
- d i** Penicillinase (also called β -lactamase) [1]
- ii** The enzyme inactivates the penicillin because it breaks open the β -lactam ring, which is essential for the antibacterial activity of the penicillin. [1]
- iii** The side-chain (R) [1]

- 3 a** Strong analgesics temporarily bind to opioid receptors in the brain, preventing the transmission of pain signals. [1]
- b i** Diamorphine contains two ethanoate esters, whereas morphine contains two hydroxyl groups. [1]
- ii** Addition-elimination or esterification [1]
- iii**



- iv** Increased risk of spread of hepatitis or HIV/AIDS due to shared needles; increased crime due to the need to fund addiction. [2]
- 4 a** Hydrochloric acid [1]
- b** $\text{CaCO}_3(\text{s}) + 2\text{HCl}(\text{aq}) \rightarrow \text{CaCl}_2(\text{aq}) + \text{H}_2\text{O}(\text{l}) + \text{CO}_2(\text{g})$ [1]
- c** Ranitidine inhibits the production of stomach acid – it is an H_2 -receptor antagonist. It binds to a receptor protein (H_2 -receptor) in the membrane of the parietal cells, which stops the normal chemical messenger (histamine) from binding to turn on the chain of events for producing acid. Ranitidine therefore prevents the production of stomach acid. [3]

- d** Active metabolites are the active forms of drugs after they have been processed in the body. Codeine is converted into morphine in cells and it is the morphine that binds to the opioid receptors.
or
Omeprazole/esomeprazole are converted into different forms that are able to bind to proton pumps.
or
Aspirin is converted into the active form – salicylic acid. [2]
- e** Number of moles of $\text{KH}_2\text{PO}_4 = \frac{15.00}{136.09}$
 $= 0.110\,20\text{ mol}$
 Number of moles of $\text{K}_2\text{HPO}_4 = \frac{15.00}{174.18}$
 $= 0.086\,12\text{ mol}$
 $[\text{base}] = 0.086\,12\text{ mol dm}^{-3}$;
 $[\text{acid}] = 0.110\,20\text{ mol dm}^{-3}$
 $\text{pH} = \text{p}K_a + \log_{10} \left(\frac{[\text{base}]}{[\text{acid}]}} \right)$
 $= 7.21 + \log_{10} \left(\frac{0.08612}{0.11020} \right)$
 $= 7.21 + \log_{10} 0.7815 = 7.10$ [3]
- 5 a** Viruses cannot replicate on their own but use the host cell's materials and processes in order to produce new viruses; they release their genetic material (RNA or DNA) into the host cell. Bacteria replicate on their own by cell division. [2]
- b** Two from: by altering the cell's genetic material by becoming incorporated into the growing DNA strand and halting its synthesis; by inhibiting the activity of enzymes within the host cell that are necessary for the formation of new viruses; by stopping the viruses from infecting host cells by preventing them from binding to the host cell surface and gaining access into the cell; by stopping the virus from leaving the host cell and infecting other cells. [2]
- c** **I** (secondary) carboxamide (amide)
II (primary) amine
III ester [3]
- d** The ability of the HIV virus to mutate readily; the HIV virus uses the host cell's own processes to replicate; because many patients in poorer countries do not have access to antiretroviral drugs. [2]
- 6 a** Antibiotics can be released into the environment through the improper disposal of medicines containing antibiotics and from animal waste. The release of antibiotics into the environment through waste water can cause damage to aquatic organisms and also result in increased resistance of bacteria to antibiotics. Antibiotics (antibacterials) are used to treat a variety of conditions but if bacteria develop resistance to antibiotics such as penicillin, these diseases can become much more difficult to cure. [4]
- b i** Low-level waste has low activity (not many radioactive nuclei decay each second to produce ionising radiation) and usually contains isotopes with short half-lives (ionising radiation is given off for only a short time). High-level waste has high activity (many radioactive nuclei decay each second to produce ionising radiation) and usually contains isotopes with longer half-lives (ionising radiation is given off for a long time). [2]
- ii** Two of: gloves/other protective clothing; tools; syringes; excreta from patients treated with radioisotopes. [2]
- iii** Low-level waste may be stored on site until it has decayed to such an extent that it can be disposed of as ordinary waste (e.g. in landfill sites or released into the sewage system) or shipped to a central site for more specialised disposal. Some low-level waste is incinerated. Low-level waste with higher activity is often buried underground (near-surface disposal) – for example, in individual concrete canisters or in concrete-lined vaults. [2]
- 7 a** Cancer – mainly breast, ovarian and lung cancer. [1]
- b** The bark of Pacific yew trees. [1]
- c** A chiral auxiliary is a chiral molecule that is bonded to a non-chiral starting material to produce a chiral intermediate. The presence of the auxiliary allows the reagent in the next stage of the reaction to approach from one side of the molecule only, forcing the reaction to follow a certain path that favours the production of one of the possible enantiomers. Removal of the auxiliary then gives the single enantiomer. [3]
- d** Plane-polarised light is passed through the sample in a polarimeter. Different enantiomers of a particular compound rotate the plane of plane-polarised light in opposite directions. An enantiomer can be identified from its specific rotation; this can be calculated from the angle

through which plane-polarised light is rotated by a sample of known concentration and path length under specific conditions.

The specific rotation of an enantiomer under a given set of conditions is characteristic of the compound and can be used to identify it by comparing to tables of literature values. [3]



ii $\lambda = \frac{\ln 2}{t_{\frac{1}{2}}}$
 $= \frac{0.693}{6.71} = 0.103 \text{ d}^{-1}$

$$\frac{N}{N_0} = e^{-\lambda t}$$

$$\frac{N}{N_0} = e^{-0.103 \times 28} = 0.0559$$

$$\text{mass of lutetium} = 0.0559 \times 10 = 0.559 \text{ mg}$$

Note: if more figures are carried through on the calculator the answer 0.554 mg is obtained. [4]

b Hair loss; nausea; fatigue; sterility [3]

c Targeted alpha therapy targets, as far as possible, just cancer cells by using monoclonal antibodies. Monoclonal antibodies can be made that target a specific type of cancer cell and can be labelled with an α -emitting radioisotope. The antibody travels through the body and attaches to just this one type of cell, carrying the radioisotope with it. Decay of the radioisotope atom produces α particles, which destroy the cancerous cell. [3]

9 a For solvent extraction, the solvents chosen must be immiscible, but ethanol dissolves in water. Improvement – use a solvent that does not dissolve in water, such as ethoxyethane or ethyl ethanoate. [3]

b i Number of moles of benzene = $\frac{1.00}{78.12}$
 $= 0.0128 \text{ mol}$
 Number of moles of methylbenzene = $\frac{10.0}{92.15} = 0.1085 \text{ mol}$
 Total number of moles in mixture = $0.0128 + 0.1085 = 0.121 \text{ mol}$
 Mole fraction of benzene = $\frac{0.0128}{0.121} = 0.106$
 Mole fraction of methylbenzene = $\frac{0.1085}{0.121} = 0.894$
 $P_{\text{benzene}} = 0.106 \times 10.00 = 1.06 \text{ kPa}$
 $P_{\text{methylbenzene}} = 0.894 \times 2.93 = 2.62 \text{ kPa}$
 $P_{\text{tot}} = P_{\text{benzene}} + P_{\text{methylbenzene}}$

$$P_{\text{tot}} = 1.06 + 2.62 = 3.68 \text{ kPa}$$

Note: more figures were carried through on the calculator to obtain this answer. [4]

ii The mole fraction of benzene in the vapour is $\left(\frac{1.06}{3.68}\right) = 0.288$, which is much higher than that in the liquid. Benzene is more volatile than methylbenzene and therefore has a greater tendency to enter the vapour phase. [2]

iii Benzene can be separated using fractional distillation. The mixture is heated in a flask with a fractionating column attached. The mixture boils and the vapour is richer in the more volatile component (benzene). The vapour rises up the column until it condenses in the cooler parts higher up. The liquid trickles down the column and is heated by vapour coming up from below. The process of boiling and condensing repeats as the vapour passes up the column. Each time the vapour boils and condenses it becomes richer in the more volatile component. Essentially pure benzene is obtained from the top of the column. [4]

c i carbonyl (ketone), alkenyl (alkene), hydroxyl (alcohol) [3]

ii 1620 cm^{-1} is due to C=C
 1680 cm^{-1} is due to C=O
 2900 cm^{-1} is due to C–H
 3400 cm^{-1} is due to O–H

The absorption for C=O is a bit lower than given in the IB Chemistry data booklet but the ranges there are just approximate. [4]

iii The organic chemicals are extracted from the urine sample and then separated into their various components using gas chromatography. Each band, as it comes out of the chromatography column, is passed directly into a mass spectrometer, where it is analysed. The mass spectrum of a compound is generally characteristic of that compound, so by comparison with the mass spectra in a database, the compound can be identified. [2]

Answers to Option D test yourself questions

- 1 **a** 3.85 dm^3 ; **b** 3.43 dm^3
- 2 **a** 4.82; **b** 4.47; **c** 4.98; **d** 4.76; **e** 4.76; **f** 8.95
- 3 **a** $0.275 \text{ mol dm}^{-3}$; **b** 4.19
- 4 0.650 g (the answer 0.648 g is obtained if more figures are carried through on the calculator)
- 5 **a** $^{115}_{50}\text{Sn}$; **b** $^{220}_{86}\text{Rn}$; **c** $^{63}_{29}\text{Cu}$; **d** $^{225}_{88}\text{Ra}$
- 6 **a** beta; **b** alpha; **c** beta; **d** beta; **e** alpha
- 7 **a** 25 mg; **b** 6.25 mg; **c** 0.0980 mg
- 8 **a** 45 d; **b** $7 \times 10^{11} \text{ y}$
- 9 **a** 800 y; **b** 168 d
- 10 **a** 0.012 min^{-1} ; **b** $8.04 \times 10^{-3} \text{ d}^{-1}$; **c** $3.30 \times 10^{-16} \text{ y}^{-1}$
- 11 **a** 134 minutes (135 minutes if all figures are carried through on the calculator); **b** 200 days; **c** 4.9×10^{15} years
- 12 **a** 29.8%; **b** 16.4%
- 13 Half-life = $1.33 \times 10^6 \text{ s}$ or 15.4 days
Mass left = $0.301 \mu\text{g}$
- 14 **a** Vapour pressure = 17.6 kPa
mole fraction of **A** in vapour = 0.455
mole fraction of **B** in vapour = 0.545
b Vapour pressure = 8.80 kPa
mole fraction of **C** in vapour = 0.682
mole fraction of **D** in vapour = 0.318
c Vapour pressure = 6.17 kPa
mole fraction of **E** in vapour = 0.494
mole fraction of **F** in vapour = 0.506
d Vapour pressure = 13.6 kPa
mole fraction of **G** in vapour = 0.176
mole fraction of **H** in vapour = 0.824
- 15 0.0156 kPa